EUROPEAN PATENT APPLICATION

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(54) Error tolerant thermometer-to binary encoder.

(57) A thermometer-to-binary encoder converts a quantity I of input digital signals, each representing one bit of an I-bit thermometer code, into a set of output digital signals each representing one bit of a corresponding binary code. The input signals are grouped into a quantity J of signal subsets, the Nth signal subset comprising the input signals representing the Nth lowest order bit of the input thermometer code and every Jth bit thereafter, each subset thereby representing a separate thermometer code derived from the I-bit input thermometer code. Each signal subset is applied as an input to a separate thermometer-to-binary encoder stage which converts the signal subset thermometer code input into a corresponding binary code output. The binary code outputs of every encoder stage are then summed to produce the set of output signals representing the binary output code corresponding to the I-bit input thermometer code.

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FIG. 1
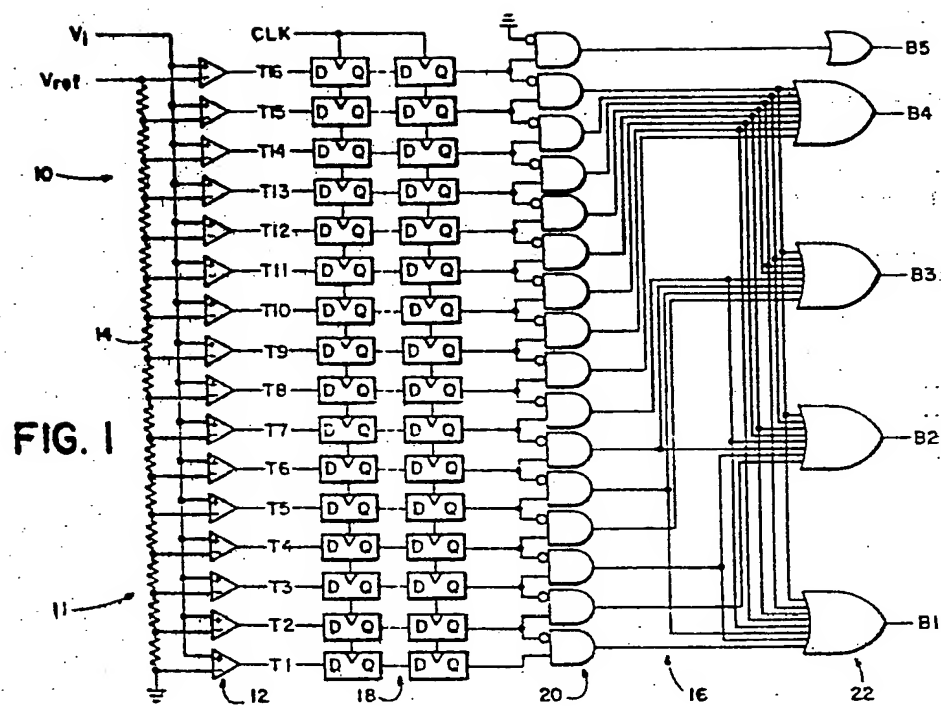
ERROR TOLERANT THERMOMETER-TO-BINARY ENCODER

Background of the Invention

The present invention relates generally to
5   thermometer-to-binary encoding systems and in par-
ticular to a thermometer-to-binary encoding system
which minimizes the error in an output binary code
resulting from an out-of-sequence error in an input
thermometer code.

10   A number may be represented by a thermometer
code wherein successive bits of a data word are
assigned progressively larger values, all of the
bits having assigned values below or the same as
the number being set to a logical true state, and
15   all of the bits having values higher than the
number being set to a logical false state. In a
typical analog-to-digital (A/D) converter, a
reference voltage is divided into a set of pro-
gressively smaller reference voltage quantum
20   levels and a comparator associated with each
quantum level compares an analog input voltage
with the voltage quantum, generating an output
true state if the input voltage is higher than the
voltage quantum reference. The outputs of all of
25   the comparators thus form the bits of a thermome-
ter code representing the magnitude of the input
voltage when arranged in order of the associated
reference voltage quantum level magnitudes.

In comparison to most other commonly used
30   codes, thermometer codes do not represent numbers
efficiently in terms of the number of bits
required. For instance, an eight bit thermometer
code can represent any one of 9 different numbers
(including 0) while a typical eight bit binary
35   code can represent 256 different numbers. There-

fore the thermometer code output of an A/D converter is usually converted by an encoding circuit to another more compact and useful binary code before being transmitted as data to external circuits.

5   A problem arises when the bits of the thermometer code are out-of-sequence, i.e., when logical-true bits in the code are separated by one or more intervening logical-false bits. This can sometimes happen when the thermometer code is pro-
10   duced by an A/D converter when sampling a high frequency signal if the individual comparators of the converter do not all switch at the same speed. For instance, if the input voltage is falling at the time it is sampled, a lower order comparator
15   which is relatively fast may switch to a low output state before a higher order comparator, which is relatively slower, switches. When the out-of-sequence thermometer code is applied as an input to a typical thermometer-to-binary encoder, the output
20   of the thermometer-to-binary encoder bears little relation to the actual magnitude of the sampled voltage. It has been shown experimentally that for many A/D converters a good approximation of the most likely particular magnitude of a sampled vol-
25   tage which produces an out-of-sequence thermometer code is obtained by simply counting the logical-true bits in the out-of-sequence thermometer code. It would be advantageous if the thermometer-to-binary encoder would produce a binary code output
30   in response to an out-of-sequence thermometer code input which would be as close as possible to this "ideal" approximation result. It should be noted that the technique of counting the logical-true bits also correctly encodes an in-sequence thermo-
35   meter code input.

Summary of the Invention

According to one aspect of the present inven-
tion, in a thermometer-to-binary encoder, an I-bit
thermometer code is converted to a set of J binary
codes by a plurality of K-bit thermometer-to-binary
encoder stages where J equals I/K. The Nth bit of
the I-bit thermometer code is applied as an input
to the (N modulo J)th encoder such that every
encoder has as its input a K-bit thermometer code
comprising every Jth bit of the I-bit thermometer
code. The binary codes produced by the encoder
stages are then summed to produce a binary code
which is equivalent to the I-bit thermometer code.
For instance a 64-bit thermometer code is divided
into a set of four 16-bit thermometer codes. The
first 16-bit thermometer code comprises the first,
fifth, ninth, etc. bits of the 64-bit code, the
second 16-bit thermometer code comprises the second,
sixth, tenth, etc. bits of the 64-bit thermometer
code, the third 16-bit code comprises the third,
seventh, eleventh, etc. bits of the 64-bit code,
and the fourth 16-bit thermometer code comprises
the the fourth, eighth, twelfth, etc. bits of the
64-bit thermometer code. The four 16-bit thermome-
ter codes are then applied as inputs to four 16-bit
thermometer-to-binary encoder stages. The four 5-
bit binary codes produced by the encoder stages are
summed to produce a single 7-bit binary code output
representing the same number as did the 64-bit
thermometer code input. (A 64-bit thermometer code
can represent 65 different numbers, so a 7-bit
binary code is needed to encode the same values.)

The "span" of an out-of-sequence error in a
thermometer code is defined as the number of inter-
vening bits between the highest order true bit and

the highest order in-sequence true bit. (An in-
sequence true bit is defined to be a true bit for
which every lower-order bit is also true.) If the
span of an out-of-sequence error in a thermometer

5   code is less than J, the binary code output of the
thermometer-to-binary encoder of the present inven-
tion will represent the count of the bits of the
thermometer code in the true state, i.e., it will
match the ideal approximation result. If the span

10 of the error is equal to or greater than J, the
binary code output will deviate from the ideal
approximation result by an amount which is substan-
tially less than the amount of deviation exhibited
by thermometer-to-binary encoders of the prior art.

15   It is accordingly an object of the present
invention to provide a new and improved
thermometer-to-binary encoder which minimizes the
deviation of the magnitude of its binary code
output from the ideal approximation magnitude

20 resulting from an out-of-sequence error in its
thermometer code input.

         The subject matter of the present invention is
particularly pointed out and distinctly claimed in
the concluding portion of this specification.

25 However, both the organization and method of opera-
tion, together with further advantages and objects
thereof, may best be understood by reference to the
following description taken in connection with
accompanying drawings wherein like reference

30 characters refer to like elements.

35

Drawings

FIG. 1 is a schematic diagram of an analog-to-binary converter of the prior art; and

FIG. 2 is a block diagram of a thermometer-to-
5   binary converter according to the present invention.

Detailed Description

A number may be represented by a thermometer code wherein each successive bit of a data word is
10   assigned a progressively larger value, all of the bits having assigned values below or the same as the number being set to a logical true (e.g. a logic "1" level) state and all of the bits having values above the number being set to a logical
15   false (e.g. a logic "0" level) state. Table I lists the decimal values associated with each allowable state of an eight bit thermometer code.

0	00000000	5	00011111
1	00000001	6	00111111
2	00000011	7	01111111
3	00000111	8	11111111
4	00001111		

20

25   TABLE I

A 16-bit thermometer code would be required to represent the numbers from 0 to 16. Binary codes
30   are more compact; only 5-bits are required to represent the numbers from 0 to 16. Table II lists the decimal values of the first 17 combinations of the standardly weighted 5-bit binary code.

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DEC	BINARY	DEC	BINARY
0	00000	8	01000
1	00001	9	01001
2	00010	10	01010
3	00011	11	01011
4	00100	12	01100
5	00101	13	01101
6	00110	14	01110
7	00111	15	01111
		16	10000

TABLE II

Referring to FIG. 1, there is depicted in block
diagram form, an analog-to-binary converter 10 of
the prior art adapted to convert an analog voltage
signal Vi to a five-bit binary code signal of equi-
valent magnitude. The converter 10 comprises an
analog-to-thermometer code converter 11, a ther-
mometer-to-binary encoder 16, and a set of latch
pipelines 18 coupling the output of the code conver-
ter 11 to the input of the encoder 16. The analog-
to-thermometer code conversion circuit 11 comprises
a set of sixteen comparators 12 and a voltage divi-
der network 14. The analog voltage signal Vi is
applied to a non-inverting input of each of the
comparators 12 while a reference voltage Vref is
applied to one end of the voltage divider network
14, the other end being grounded, thereby producing
a series of progressively lower reference voltage
quantum levels each of which is applied to an
inverting input of a corresponding comparator 12.
Each comparator 12 includes a difference amplifier
having an output which saturates to a high (1) logic

level output state if the input voltage is suffi-
ciently higher than its voltage reference level or
saturates to a low (0) logic level output state if
the input voltage is sufficiently lower than its
5 reference voltage. For instance, if the input vol-
tage is higher than the reference voltage applied to
the 5th comparator (i.e., the comparator producing
the 5th lowest order thermometer code bit T5) but
lower than the voltage applied to the 6th compara-
10 tor, the outputs of the 1st through the 5th compara-
tors (T1-T5) will all be high while the outputs of
the 6th through the 16th comparator (T6-T16) will
all be low. The outputs (T1 through T16) of all of
the comparators 12 thus collectively appear as a 16-
15 bit thermometer code representing the magnitude of
the input voltage Vi as any one of seventeen
discrete numbers from 0 to 16 inclusive.

The thermometer code output of the converter
circuit 11 is latched onto the input of the encoding
20 circuit 16 on receipt of a series of clock (CLK)
signals by the latches of latch pipelines 18. The
encoding circuit 16, which converts the thermometer
code to a more compact and useful 5-bit binary code,
comprises a set of AND gates 20 and a set of OR
25 gates 22, one such AND gate corresponding to each
thermometer code input bit and one such OR gate
corresponding to each binary code output bit. Each
thermometer code bit output of a corresponding latch
pipeline 18 is applied to a non-inverting input of
30 the corresponding AND gate 20 and to an inverting
input of the AND gate 20 associated with the next
lower order thermometer code bit, if any. The
inverting input of the AND gate associated with the
highest thermometer code bit T16 is grounded. The
35 outputs of the sixteen AND gates 20 are connected to

inputs of the OR gates 22 such that the output of
one OR gate 22 comprises the first (rightmost) bit
B1 of the binary code corresponding to the ther-
mometer code appearing at the conversion circuit
5   input, while the outputs of the other OR gates
comprise the second through the fifth bits B2-B5 of
the binary code. More specifically, the AND gates
20 and OR gates 22 are interconnected to effect the
following Boolean relations between the bits of the
10   thermometer and binary codes, where the "*" symbol
represents an AND function, the "+" symbol repre-
sents an OR function, and the "/" symbol preceding a
bit reference character indicates a NOT function:

15   B1 = (T1*/T2)+(T3*/T4)+(T5*/T6)+(T7*/T8)+(T9*/T10)
        +(T11*/T12)+(T13*/T14)+(T15*/T16)

     B2 = (T2*/T3)+(T3*/T4)+(T6*/T7)+(T7*/T8)+(T10*/T11)
        +(T11*/T12)+(T14*/T15)+(T15*/T16)

20
     B3 = (T4*/T5)+(T5*/T6)+(T6*/T7)+(T7*/T8)+(T12*/T13)
        +(T13*/T14)+(T14*/T15)+(T15*/T16)

     B4 = (T8*/T9)+(T9*/T10)+(T10*/T11)+(T11*/T12)
25   +(T12*/T13)+(T13*/T14)+(T14*/T15)+(T15*/T16)

     B5 = T16

     If the analog input voltage Vi is insuffi-
30   ciently larger or smaller than the quantum reference
voltage applied to any one of the comparators 12,
the comparator output will be at an invalid logic
level, neither logically high nor low, but at an
intermediate level wherein minor variations of the
35   input or reference voltages may swing the comparator

output to either its high or low level output state.
Also, if the analog input voltage is slewing past
the reference quantum levels at a rate faster than
the response time of the comparators, one or more
5   comparator outputs may be simultaneously in an
intermediate invalid state at the times they are
latched by the first latches in latch pipelines 18.
Latch pipelines 18 are provided to stabilize any
invalid thermometer code bit before applying the bit
10   to the logic gate portion of encoder 16.   Each
pipeline latch is of the type having a positive
feedback circuit such that the output will be driven
toward its high logic level state if its input
voltage is slightly larger than a threshold voltage,
15   and will be driven toward its low logic level state
if its input voltage is slightly smaller than the
threshold voltage.   After passing through a
succession of such latches in a pipeline, the
probability that a thermometer code bit generated
20   by a comparator 12 will be stabilized to a 0 or 1
logic level as it reaches the input to the encoder
16 is very high.
        While latch pipelines 18 stabilize the indivi-
dual converter 11 output bits, they do not prevent
25   out-of-sequence errors in the thermometer code
applied to the encoder 16 input.   In an out-of-
sequence error, one or more lower order bits of the
thermometer code are in a 0 state while one or more
higher order bits are in a 1 state.   For example,
30   the 8-bit 00100111 thermometer code contains an
out-of-sequence error.   The higher order bit in the
sixth position from the right is in the 1 state
while two lower order bits bit in the 4th and 5th
positions from the right are in the 0 state.   This
35   type of error can occur in an analog-to-thermometer

code converter 11 when the frequency of the analog
input signal Vi is high and the switching speeds of
comparators 12 or the thresholds of latches 18 are
not suitably matched. When Vi changes rapidly from
5   a high to a low value, the output of a lower order,
relatively fast, comparator 12 may drop below the
threshold of the first latch of its corresponding
latch pipeline 18 before the output of a higher
order, relatively slower, converter drops below the
10   threshold of its corresponding pipeline's first
latch. If the CLK signal clocks the latches 18
after the output of a lower order comparator 12
drops below its corresponding latch input 18 thres-
hold, but before the output of the higher order
15   converter drops below its corresponding latch in-
put, an out-of-sequence error results. An out-of-
sequence error can also occur when the input signal
Vi rapidly increases.

        A thermometer code containing an out-of-se-
20   quence error is passed on to the input of the
thermometer-to-binary code converter 16 and the
resulting binary code output of the converter bears
little relation to the actual sample voltage Vi
magnitude at the moment of sampling. The actual
25   magnitude of the voltage Vi is likely to be between
the value of the highest order in-sequence bit in a
1 state and the highest order out-of-sequence bit
in a 1 state. For instance, the magnitude of the
voltage Vi which produced an out-of-sequence ther-
30   mometer code 0000000010001111 is most likely to be
between 4 and 8. For many A/D converters of the
type shown in FIG. 1, an "ideal" approximation of
the particular magnitude of a sampled voltage pro-
ducing a out-of-sequence error is obtained by sim-
35   ply counting the bits in the 1 state in the out-of-

sequence thermometer code. According to this ideal
approximation, the magnitude of Vi which would pro-
duce the example out-of-sequence thermometer code
is most likely to be 5 since there are five logic
5　level 1 bits in the code. However, if such an out-
of-sequence thermometer code were applied to the
thermometer-to-binary encoder 16 of FIG. 1, the
resulting 5-bit binary code output would be 01100,
a decimal 12, for a deviation from the ideal ap-
10　proximation of 7.

　　The deviation of the output of the encoder
circuit 16 of FIG. 1 from the ideal approximation
will always be positive and can be much larger.
For instance, if the out-of-sequence thermometer
15　code were 1011111111111111, the resulting binary
code would be 11110 (decimal 30) when the ideal
binary output code should be 01111 (decimal 15), a
deviation from ideal of 15.

　　An improved version of the thermometer-to-
20　binary encoder 16, still within the realm of prior
art, can be constructed by rearranging the connec-
tions of the outputs of the AND gates 20 and the
inputs of the OR gates 22 in such a fashion as to
make the outputs of the OR gates form a Gray-code
25　equivalent in value to the thermometer code input.
This encoder can then be fed through a Gray-to-
binary encoder to complete the thermometer to bi-
nary conversion. The designs of such binary-to-
Gray and Gray-to-binary encoders are well known in
30　the art and are also discussed in copending U. S.
Patent Application No. ＿＿＿＿＿＿ entitled
"Thermometer-To-Adjacent Binary Encoder" filed
＿＿＿＿＿＿＿＿＿＿＿ which is incorporated herein by
reference. Using such a thermometer-to-Gray-to-
35　binary encoder reduces, but does not eliminate,

encoding errors resulting from out-of-sequence
thermometer code inputs. The error between the
thermometer-to-Gray-to-binary encoder's output and
the "ideal" approximations can be shown to appear
5   somewhat random in nature (i.e., both positive and
negative) and is limited to less than three times
the span of the out-of-sequence error in the ther-
mometer code input.

     Referring to FIG. 2, an encoder 30, depicted
10   in block diagram form, is adapted to convert a
first set of I digital signals, representing an I-
bit thermometer code, into a second set of digital
signals representing a corresponding binary code,
with the output binary code exhibiting minimal
15   deviation from the ideal approximation result when
the input thermometer code contains an out-of-
sequence error. In the example of FIG. 2, the
number of bits (I) of the thermometer code is 64,
the bits of the code being labeled from T1 to T64
20   in order of their relative magnitudes, the lowest
order bit being T1. The thermometer code signals
are grouped into J subsets of K signals each, and
each signal subset is applied as an input to a
separate one of J thermometer-to-binary encoder
25   stages 32, each comprising either a thermometer-to-
binary encoder or a thermometer-to-Gray-to-binary
encoder as described above. In the example of FIG.
2, the integer J is 4 and the integer K is 16 so
that there are 4 encoder stages 32, each converting
30   a 16-bit thermometer code to a 5-bit binary code.
The lowest order bit T1 of the 64-bit thermometer
code is applied as a lowest order bit of the 16 bit
thermometer code input of a first encoder stage 34.
Similarly, the next 3 lowest order bits (bits T2-
35   T4) of the 64-bit thermometer code are applied as

the lowest order input bits to the second through the fourth encoder stages 36, 38 and 40 respectively. The next set of four lowest order bits (bits 5 through 8) of the 64-bit thermometer code are

5 applied as the next lowest order input bits of the 16-bit thermometer code input to the first through the fourth encoder stages 32, respectively. The remaining progressively higher order bits of the 64-bit thermometer code are also grouped and

10 applied as progressively higher order input bits to the encoder stages 32 such that the Nth encoder stage, where N is an integer from 1 through J (e.g. 4), has as its input a K-bit (e.g. 16-bit) thermometer code, comprising the Nth lowest order bit of

15 the I-bit (e.g. 64-bit) thermometer code and every Jth (4th) bit thereafter in ascending order.

In the embodiment of the invention depicted in FIG. 2, each encoder stage 32 has a five-bit binary output code similar to that of Table II above. The

20 five-bit binary code output of each encoder stage is applied as an input to a summer 42 which generates as its output a seven-bit binary code representing the sum of the binary code outputs of encoders 32, which sum can range from 0 to 64. Circuits capable

25 of performing the function of summer 42 are well known in the art and are not further detailed herein.

Assuming by way of example that a 64-bit thermometer code input to encoding circuit 30 repre-

30 sented the decimal number 21, the 21 lowest order bits of the code would be high and the 43 higher order bits would be low. The 16-bit thermometer code input to the first encoder stage 34 would be 0000000000111111 (a decimal 6), and the thermometer

35 code inputs to the second, third and fourth encoder

stages 36, 38, and 40 would all be 0000000000011111
(a decimal 5). The first encoder stage 34 would
then convert its thermometer code input to a binary
equivalent of decimal 6 while the other encoder

5   stages would convert their thermometer code inputs
to the binary equivalent of decimal 5. Summer 42
would then sum the four encoder stage 32 outputs to
produce the 7-bit binary equivalent of decimal 21,
0010101.

10 By grouping the bits of the I-bit thermometer
code into subsets, separately encoding each subset,
and summing the binary code output of each encoder
stage 32 as described hereinabove, the deviation of
the sum from the ideal approximation of an out-of-

15 sequence thermometer code is reduced over that
which would typically be produced by a single stage
64-bit thermometer-to-Gray-to-binary or thermometer-
to-binary code converter. For instance, if the 64-
bit thermometer code input was 00...001000111111111111,

20 the thermometer code inputs to the first, second
and third encoder stages 32 would all be 00...00111
(a decimal 3), while the input to the fourth enco-
der stage would be 00...001111 (a decimal 4). As
can be seen, none of these thermometer code subsets

25 contain an out-of-sequence error. The output of
the summer 42 would be the binary equivalent of a
decimal 13 which is the ideal approximation corres-
ponding to the out-of-sequence thermometer code
since there are thirteen logic level 1 bits in the

30 thermometer code. If such an out-of-sequence ther-
mometer code were applied to a single stage 64-bit
thermometer-to-binary encoder, similar in design to
the encoder of FIG. 1 but having 64 rather than 16
inputs, the output of the encoder would be 00111000

35 (a decimal 28), a deviation of 15 from the ideal

approximation.

Similarly, if such an out-of-sequence thermom-
eter code were applied to a 64-bit thermometer-to-
Gray-to-binary encoder, the output of the encoder
5   would 0010011 (a decimal 19), a deviation of 6 from
the ideal approximation.

The span of the out-of-sequence error in the
thermometer code 00...0010001111111111111, i.e., the
number of intervening bits between the highest
10   order 1 bit and the highest order in-sequence 1 bit
in the thermometer code, is 3. Whenever the span
of an out-of-sequence error is less than the number
(J) of encoder stages 32, the input to each encoder
stage 32 will be free of out-of-sequence errors and
15   the output of summer 42 will always equal the ideal
approximation value of an out-of-sequence thermo-
meter code input. In contrast, the output of a
single stage prior art encoding system will always
differ from the ideal approximation value, often by
20   a substantial amount as illustrated hereinabove.

When the span of an out-of-sequence error is
greater than or equal to J, one or more of the
thermometer code inputs to encoder stages 32 may
also contain an out-of-sequence error. However the
25   span of the error in the K-bit thermometer code
input to any one encoder stage 32 will be smaller
than the span in the error in the I-bit thermometer
code. In fact, the spans of the out-of-sequence
errors in the K-bit thermometer codes will be at
30   most the span of the error in the I-bit thermometer
code divided by J.

Use of thermometer-to-Gray-to-binary encoders
provides an advantage over use of direct
thermometer-to-binary encoders as encoders 32 of
35   FIG. 2. Since the errors in the outputs of the

thermometer-to-Gray-to-binary encoders resulting
from an out-of-sequence input thermometer code tend
to be randomly distributed, the errors will tend to
cancel one another when the encoder stage outputs

5   are summed. The difference between the ideal
approximation value of an out-of-sequence thermome-
ter code and the output of the summer 42 is on the
average reduced by a factor of the square root of J
over the difference between the ideal and the

10   actual output of a single stage encoder circuit of
the prior art. Thus if J is 4, and the out-of-
sequence span is larger than or equal to 4, the use
of thermometer-to-Gray-to binary encoders in the
circuit of FIG. 2 will produce an output which on the

15   average deviates from the ideal approximation by
roughly half the amount by which the output of a
64-bit, single stage thermometer-to-binary encoder
circuit deviates from the ideal approximation.

While a preferred embodiment of the present

20   invention has been shown and described, it will be
apparent to those skilled in the art that many
changes and modifications may be made without de-
parting from the invention in its broader aspects.
For example, while the invention as illustrated in

25   FIG. 2 converts a 64-bit thermometer code to a
binary code utilizing four encoder stages 32, other
thermometer code sizes (I) and/or other numbers (J)
of encoder stages may be utilized in a similar
fashion according to the present invention. Also,

30   while the invention was described as having encoder
stages 32 comprising thermometer-to-Gray-to-binary
encoders or thermometer-to-binary encoders of the type
illustrated in FIG. 1, other thermometer-to-binary
encoders may be used and are particularly advanta-

35   geous if their out-of-sequence output errors are

limited and tend to cancel one another. As an
example, if half of the encoders 32 are thermometer-
to-binary encoders as in FIG. 1 and the other half
are similarly constructed but using inverted logic

5   whereby the errors from the first half will always
be positive and the errors from the second half
will always be negative, the errors will tend to
cancel. The claims are therefore intended to cover
all such changes and modifications as fall within

10   the true spirit and scope of the invention.

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Claims

1. A method for producing a binary code
corresponding to a first thermometer code, each bit
of said first thermometer code being represented by
5   the state of a separate one of a set of digital
signals, the method comprising the steps of:

        grouping said signals into selected sub-
sets each representing a further thermometer code;

        converting each said signal subset thermo-
10   meter code into a corresponding binary code; and

        summing the binary codes representing each
signal subset to produce the binary code
corresponding to said first thermometer code.

15   2. The method according to claim 1 wherein
digital signals as grouped into a selected subset
represent bits spaced in said first thermometer
code by a predetermined interval.

20   3. A method for converting a first set of I
digital electronic signals representing an I-bit
thermometer code into a second set of digital elec-
tronic signals representing a corresponding binary
code, wherein I is a selected integer, the method
25   comprising the steps of:

        a. grouping said first signal set into a
plurality, J, of first signal subsets, each Nth
first signal subset comprising the Nth signal of
said first signal set and every Jth signal there-
30   after, each first signal subset thereby repre-
senting a separate thermometer code;

        b. converting each said first signal
subset into a corresponding third digital electron-
ic signal subset representing a binary code corre-
35   sponding to the thermometer code represented by a

said first signal subset; and

       c.   summing all third digital electronic
signal subsets to produce said second set of digi-
tal electronic signals representing said binary

5   code corresponding to said I-bit thermometer code.

       4.   The method of claim 3 wherein step b
comprises the substeps of:

       d.   converting each said first signal

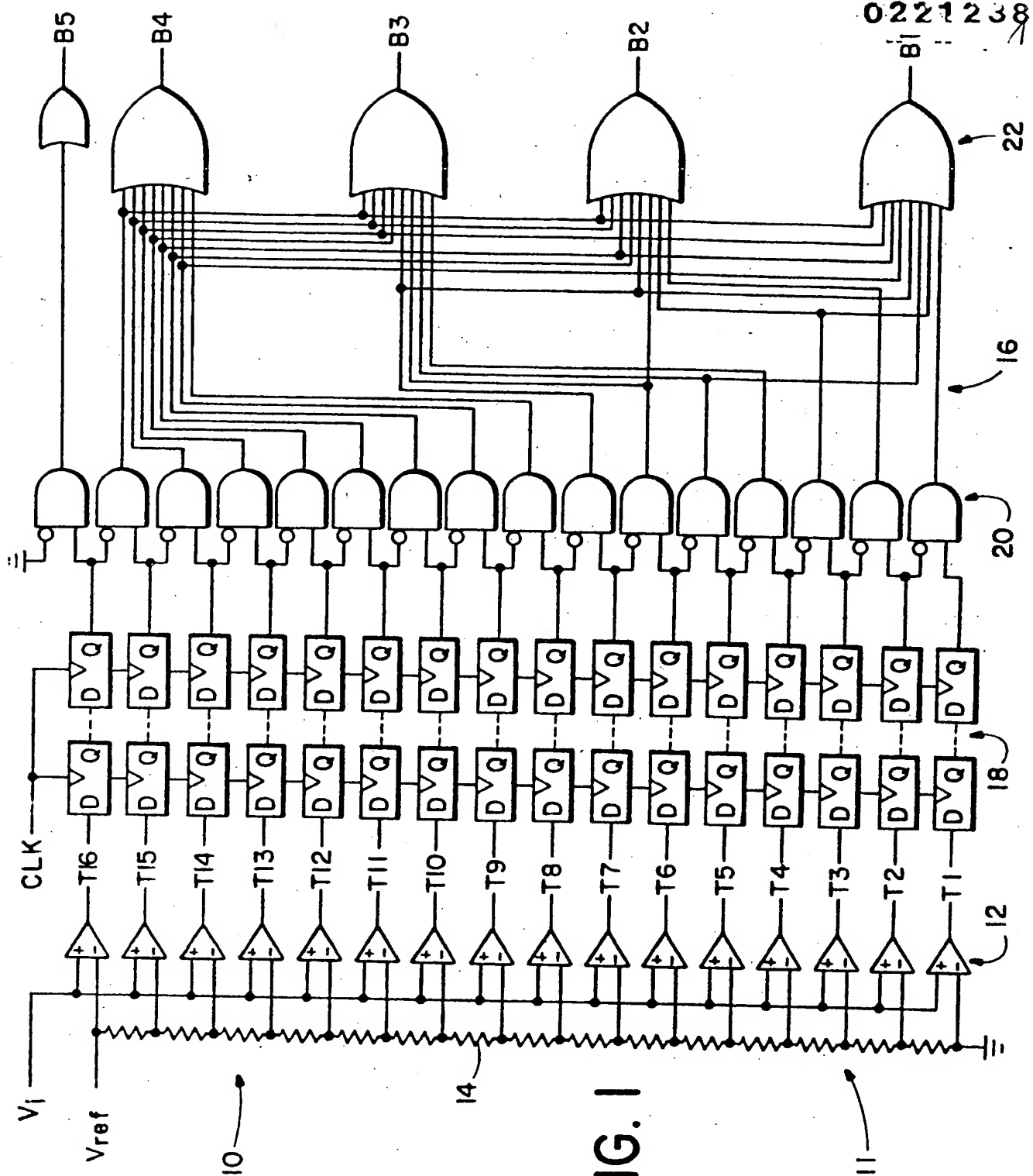10   subset into a corresponding Gray code, and

       e.   converting each said Gray code into
said corresponding third signal subset representing
a said binary code.

15   5.   An apparatus for converting a first set of
I digital electronic signals representing an I-bit
thermometer code into a second set of digital elec-
tronic signals representing a corresponding binary
code, wherein I is a selected integer, the appara-

20   tus comprising:

       means for grouping said first signal set
into a plurality, J, of first signal subsets, each
Nth first signal subset comprising the Nth signal
of said first signal set and every Jth signal

25   thereafter, each first signal subset thereby repre-
senting a separate thermometer code;

       means for converting each said first sig-
nal subset into a corresponding third digital elec-
tronic signal subset representing a binary code

30   corresponding to the thermometer code represented
by a said first signal subset; and

       means for summing all third digital elec-
tronic signal subsets to produce said second set of
digital electronic signals representing said binary

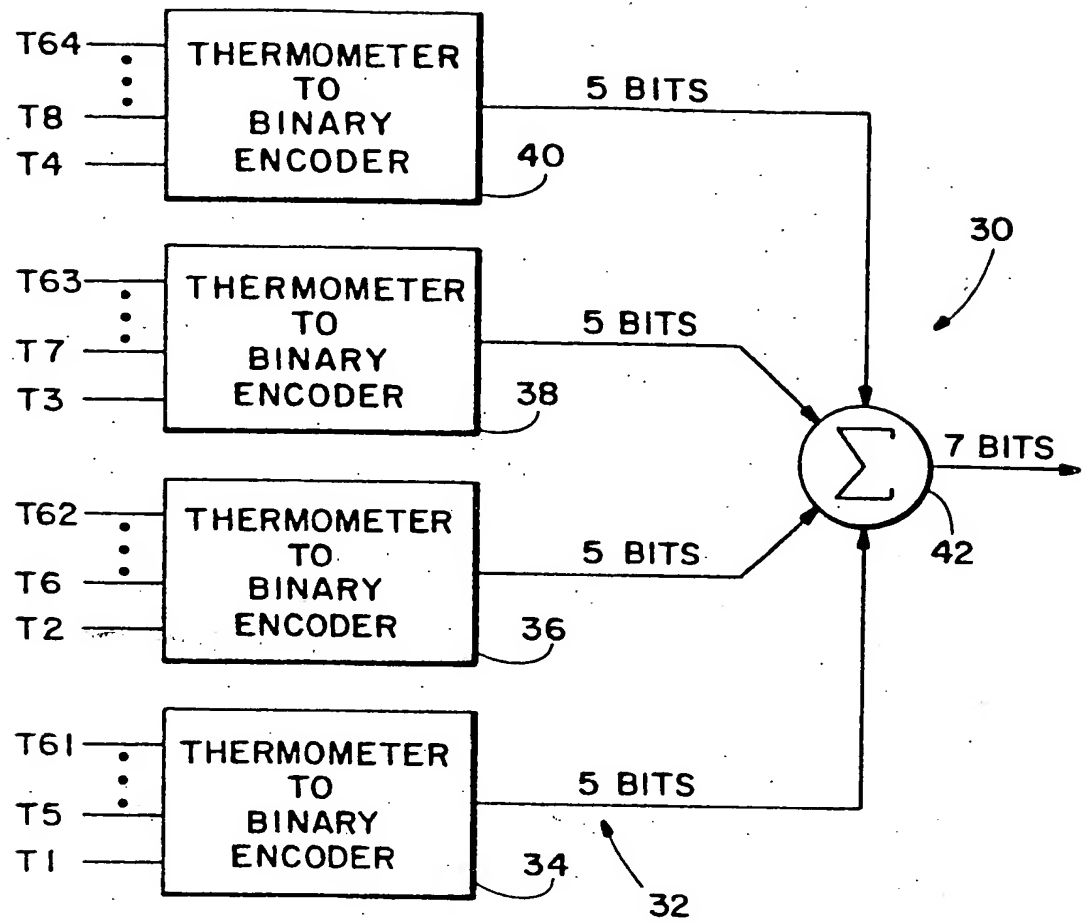35   code corresponding to said I-bit thermometer code.

FIG. I

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T64
·
·
T8   THERMOMETER TO BINARY ENCODER   5 BITS
T4   40

T63
·
·
T7   THERMOMETER TO BINARY ENCODER   5 BITS
T3   38

T62
·
·
T6   THERMOMETER TO BINARY ENCODER   5 BITS
T2   36

T61
·
·
T5   THERMOMETER TO BINARY ENCODER   5 BITS
T1   34   32

30

Σ 7 BITS

42

FIG. 2

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